Water & Energy Cycles

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Water & Energy Cycles

Critical Science Questions

Existing Roadmaps: *Given what we have heard about UAV potential, what of the 2007-2015 Roadmap goals could be addressed from a SUBORBITAL platform?*

- River Characteristics (static and variable) Topography, Roughness / Discharge (7,000 rivers) – Floodplain assessment

- Cloud properties and extent (ice content, radiative, profile)

- Precipitation – especially storm tracking – hurricanes, blizzards, etc.

- Snow water equivalent

- Water and temperature profiles in the atmosphere

- Soil moisture (esp. higher spatial resolution and/or deeper depths)

- Surface evaporation (Land & Ocean)

Other Roadmap Possibilities: *Are there other things that should be in the Roadmap now that we see what is possible?*

- Water quality
- Land subsidence for groundwater change
- Snowfall
- Soil characteristics (freeze/thaw condition, type)

- Ocean surface properties (salinity, temperature, wind)

- Boundary layer dynamics

- Drought (what is it? Vegetation health, soil deficit)

Water & Energy Cycles

Critical Science Questions

Phasing Observations: *How would we phase the critical observations in our Earth Science focus area that are most suitable for the suborbital platform realm?*

- *Overarching Concern: Global Measurement Capability (internationally)*

- River Characteristics
  - Smart flying (sensor control direction?)
  - Multiple sensors
  - Global Measurement capability (international)

- Cloud properties
  - Tandem flying (vertically and horizontally)
  - Cloud fly through ability
  - Altitude concerns (for above/in cirrus clouds)
  - Multiple sensors, complex sensors?

- Soil Moisture
  - Large antenna required (for P-band or spatial resolution)

- Snow Water Equivalent
  - High spatial resolution
  - Difficult flying (topography issues, poor conditions)

- Storm tracking
  - Bad weather flying

- Vegetation Characteristics (Type & health)
- Boundary Layer assessment
  - Small UAV piloting (safety)
  - Formation flying (3-D assessment)
  - Multiple sensor & sensor accuracy

- Water Quality

Water & Energy Cycles – Cloud Properties

<u>Critical Observation</u>: Cloud Properties

<u>Observation / Measurement Definition</u>: Describe the phenomenon you want to observe. Describe what you need to measure.

- In situ micro-physics of all clouds.

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Better understanding of cloud dynamics should lead to improve representation in weather and climate models. This could result in improved precipitation forecasting as well as radiation balances.

Explicitly state the advantage of using a suborbital platform for this measurement.

- Can't get in situ of clouds any other way!

Identify other cross-cutting areas impacted by this observation.

- GPM, Cloudsat & Calipso cal/val instrument.
- Useful for Weather, Climate focus areas as well.
- Synergies with Atmospheric Composition FA and ARM program

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

1. Passive microwave Imager (from high altitude for ocean & land coverage and movement capability to follow systems). Ideally 10 – 600 Ghz range. Minimally 19-183 Ghz range.
2. Dual-pole Multiple Frequency microwave radar (13, 35, 94 Ghz. ?)
3. in-situ sensors – cloud particle imagers, perhaps others?
4. Lidar
5. Smart drop sonde

Water & Energy Cycles – Cloud Properties

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Minimum of two aircraft (one high imager, one in situ). Multi in-situ would be preferred b/c of fine spatial & temporal scale dynamics.

- Altitude: Imager needs high altitude capability (lower stratosphere, 25km?), lower bound would be order 1 km. In situ fliers would require similar altitude range and go all the way down to the surface.

- Formation flying: in situ flight path controlled by data retrieved from high flier. Updrafts in clouds could provide some lift and enhanced endurance.

- Endurance: For Imager at least 24-48 hours though longer (~1 week) would provide much greater science return. In situ system to provide coverage for 24-48 hours (perhaps by using multiple successive fliers).

- In situ samplers would benefit to having some vertical control, including multiple ascent/decent capability, spirals through the clouds and boundary layer.

- Range: Having 10,000km transport range for imager (prior to hovering) would be helpful. Range for in situ fliers on order of 10 kms.

- Positional information required to accuracy of 10 meters for all systems. Good attitude position accuracy (0.1 degree) for imaging aircraft.

- All season, including hurricanes and blizzards.
- Tropics and mid-latitudes (both over land and ocean).

- One option would be to have a high altitude storage ship that contains many of the smaller in situ sampling UAVs. The Imager communicates to the storage ship location and distribution of small samplers. Storage ship would require similar range & altitude as imager. Endurance could be less (24-48 hr range). This frees up the in situ samplers to be minimal in propulsion.

Communication needs such as real-time data or instrument control

- Imager needs to be able to communicate flight instructions to in situ platforms. Data download from in situ platforms needs to occur in flight (near real time) in case in situ fliers are lost during flight. In situ platforms might require smart systems to turn on/off and direct their instruments while in flight, based on its own observations or imager direction.

Water & Energy Cycles – Cloud Properties

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a “day-in-the-life” of the mission.

- Aircraft & instruments are shipped to base of operations. Could require fast (1-3 days) action from off shelf to shipping, integration, and launching into action.
- Imager hovers or circles in region of interest and looks for critical environmental characteristics. It then tasks the release and direction of the in situ samplers (perhaps using a storage ship as a mechanism).
- Upon activation, in situ samplers fly in clouds, have two-way communication with Imager ship, and return observation data to Imager/Storage ship and/or directly to ground or satellite if possible. In situ samplers may safely hover down to earth surface upon completion or exhaustion (biodegradeable? Collectable for reuse?). In situ samplers might be requested to take observations on descent.
- Mission data is reviewed by a “mission control” and then Mission plus (analyzed?) observations data is reviewed by larger team for improved performance in future uses.

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

- Mostly captured in “day in the life”. Transportable to Global operations excluding polar regions. (beyond 70 degrees?). Could be used in directed field campaign mode as well as continuous automated observation.

Identify any special or unique platform or mission issues

- In situ aircraft should not influence its own measurements or the cloud evolution (via chemical or heat exhaust etc.)
- Aircraft need to be able to survive and operate in harsh cloud condition. Although with relaxed flight path control.

Summarize the key elements of the mission concept for this measurement.

- Two types of vehicles in this mission – both high altitude and durable.
- One (the Imager) with good position and attitude control for observations, the other (the in situ) able to take observations at all levels of atmosphere.
- Having multiple in situ (10-100) would strongly enhance science return, even if they were lightweight (<2 kg). Would also allow multiple type of in situ & sensor combination that are more tailored for area of deployment as well as information retrieved by the imaging ship (including returned information from “early” deployed in situ observer).

Water & Energy Cycles – River Discharge

<u>Critical Observation</u>: River Discharge

<u>Observation / Measurement Definition</u>: Describe the phenomenon you want to observe. Describe what you need to measure.

- River discharge – the volume of water flowing in a river, at multiple points. In order to obtain this, we need two things:
  - River geometry, obtain from lidar mapping
  - River heights, obtained from altimetry.

Explicitly state how this observation and measurement supports this Earth Science focus area.

- These observations are critical for global and regional water balance studies.

Explicitly state the advantage of using a suborbital platform for this measurement.

- High spatial accuracy. If using lidar the ability to fly underneath (some) cloud covers would be advantageous. Advantage being able to dynamically do measurements up/down rivers. Obtain geometry by hand is extremely costly (and difficult).

Identify other cross-cutting areas impacted by this observation.

- Critical information for other agencies (USGS, EPA, etc.). Also important information for oceanography and coast zone studies. Can also use the lidar measurements for floodplain mapping.
- Micro-submersible technology could complement or used as a co-driver.

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- These two would be on different platforms:

1. Geometry – Scanning Lidar – 25kg, 0.2 m^3, 500 watts.
2. Stage Height – Dual freq. radar (to help mask out vegetation induced roughness). 200kg, 1-5 kilowatts. Size depends on antenna size. Also C-band along-track radar interferometer on both platforms for additional calibration and cross platform comparison.

Water & Energy Cycles – River Discharge

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Location: Global land areas.
- Altitude: 5-10 km for SAR (echo shouldn't interfere with emittance.) On clear days both can fly in the 5-10km range. Low to the ground for Lidar can be helpful but removes C-band data.
- Endurance: As long as it takes to fly the river channel, could be 1-24+ hours – depending upon desired level of resolution (primary channels, secondary channels, tertiary etc.)
- Season: Geometry is best done during low flow (can be late summer/early fall). River heights done year-round, especially during higher flow (after snowmelt).
- Frequency – The geometry needs to be done a few times a river. The river discharge could be on demand or weekly. Freq. is going to be dictated by the number of rivers and what extent of each is desired to be covered.

- Two Platforms

- Special Flight characteristics – Each might need to be able to follow the river's path. This could be done by coordinating with on board instruments.

- If flown during non-calm conditions the radar platform would require some precision flying in rough conditions.

- High precision knowledge of sensor footprint required.

Communication needs such as real-time data or instrument control

- The instrument must be tied to aircraft directional control.
- Communications with base could be limited to housekeeping data and basic data quality.

Water & Energy Cycles – River Discharge

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

- Option 1:
    - The Lidar platform is sent out to fly the length of the desired river channel. The lidar measures the geometric characteristics of the river and its path and uses that to control the flight track of the aircraft. Aircraft returns to base and information is extracted and analyzed.
    - At some later time the Radar platform flies the same river channel, though it might not necessarily fly the entire track, just the sections over which the river surface heights are desired.
- Option 2: (assuming each has C-band along track radar)
    - Both platforms are sent out to fly the length of the desired river channel.
    - The lidar measures the geometric characteristics of the river and its path.
    - This path information is used to control its flight track as well as the SAR platform behind it.
    - Upon return information is extracted and analyzed.
- Option 3: On demand.
    - During critical events (or during/just after heavy (upstream) rains) the SAR platform might be detailed to fly over a given river.
    - This would probably only be done after the first platform had flown over it at least once.

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

- Flight profile is going to be determine by which section of the river is desired (if not all).

Identify any special or unique platform or mission issues

- Lidar must fly underneath clouds and close to the ground if possible and safe.
- Accurate position precision for both platforms is required.
- Stable platforms helpful for improved mapping accuracy.
- SAR platform should be high enough for robust measurements (minimum 4 km.?)

Summarize the key elements of the mission concept for this measurement.

- There is a tremendous opportunity here and the platforms can operate separate or together to acquire critical information.
- Suborbital allows the ability to obtain hard to get (if not impossible) measurements globally.
- Allow for accurate mapping of floods in inundated areas.
- The UAV platforms must be stable and precise in position knowledge to obtain the data quality required.

Water & Energy Cycles – Snow–Liquid Water Equivalent

Critical Observation: Snow – Liquid Water equivalent

Observation / Measurement Definition: Describe the phenomenon you want to observe. Describe what you need to measure.

- Measuring the water stored in the snowpack, at very high spatial resolution (~50 m). Also getting snowpack characteristics such as depth, density, wetness, age, emissivity, albedo, etc.

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Getting the melt quantity and timing has significant application for decision makers. Also, knowledge of the snowpack is important for water budget studies. Would allow for improvement in prediction of snow (weather & climate) as well as understanding the climate data record provided by snow cover measurement.

Explicitly state the advantage of using a suborbital platform for this measurement.

- Higher spatial resolution and better temporal revisit timing. Ability to resolve measurement in mountainous regions…where there happens to be a lot of snow.

Identify other cross-cutting areas impacted by this observation.

- This would be of interest to weather and climate focus areas.
- Many Federal, State, and local agencies want this type of information (for example, USGS, USDA, NOAA, Western Governors Assoc., etc.)
- Useful for NPOESS calibration

Observation / Measurement System Requirements: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

- Dual Freq. SAR (C & Ku band)
- Dual Freq. Radiometer (K & Ka band)
- Visible and Thermal camera
- This might be 300kg for both.
- Total power 1kilowatt

- Must be able useable in cold season and mountain environments.

Water & Energy Cycles – Snow–Liquid Water Equivalent

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Location: Primarily, seasonally snow covered regions over the globe. Secondarily, in permanent snow covered regions and regions where snow is over ice / sea ice.
- Altitude: near surface (100m) to lower altitudes (<10 km)
- Endurance: 24 hrs. Less is allowable for complex terrain flights (see below)
- Season: (local) Fall, Winter, Spring primarily.
- Frequency: Able to maintain 70-80% duty cycle in a week, and sustain this over the snow season (this could be >6 months).
- Aircraft and footprint location precision: <10 meters
- Special Flight Characteristics: Being able to fly over complex terrain (mountains) and doing precise height over ground altitude (within a few meters precision), while keeping a relatively stable instrument attitude (3° pitch, 5° roll, 3° yaw). Sixty degree roll angle for instrument calibration (non-show stopper, other calibration possibilities considerable).
- Ability to drop sondes of some undefined characteristics would be useful. This would require the development of the appropriate small in-situ sensors.
- Multiple platforms would enable greater spatial coverage (this could be critical for doing more than just “science research” i.e. providing information for applications). Exact coverage would depend upon altitude and sensor specifics.

Communication needs such as real-time data or instrument control

- Two-way Housekeeping data for instrument health and limited flight control.

Water & Energy Cycles – Snow–Liquid Water Equivalent

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

- Aircraft and instrument are transported to "host" airport. Necessary calibration and validation is done on sensors suite.
- Aircraft is programmed with flight line instruction. This could be driven by event (recent snowfall, field experiment desires, or season long monitoring of selection basins).
- Aircraft flies and sensor observes, potentially drops mini in situ snow sensors. Aircraft may be doing complex flight path, either to hit particular ground targets, keep a constant altitude, or topographic avoidance maneuvers.
- Aircraft returns to airport. Data is downloaded (should be doable in less than an hour). Aircraft refreshed for new flight.

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

- Flight profiles and maneuvers would depend upon location of observation.
- Geographic coordinates: Primarily in seasonally snow covered regions.

Identify any special or unique platform or mission issues

Ability to handle mountain terrains and (limited) winter storm conditions.
Ability to operate over populated region (safety, noise).
Maintain the attitude of the aircraft in the mountain regions.

- Summarize the key elements of the mission concept for this measurement.

A Suborbital platform that can carry and provide suitable stability for the suite of instruments (critically the active/passive microwave instruments) in the areas and times of interest (mountains, winter).

Water & Energy Cycles – Soil Moisture & Freeze/Thaw states

<u>Critical Observation</u>: Soil Moisture & Freeze/Thaw states

<u>Observation / Measurement Definition</u>: Describe the phenomenon you want to observe. Describe what you need to measure.

- Characteristics of water in soil (in presence of vegetation):
  1. Surface soil moisture (0-5cm, i.e. L-band)
  2. Deep soil moisture (5cm – 5m, i.e. P-band or longer wavelengths)
  3. Freeze/thaw state (surface, i.e. L-band)

Explicitly state how this observation and measurement supports this Earth Science focus area.

- Soil moisture is on the water & energy cycle roadmap (as well as climate and weather roadmaps) because of its critical role in determining fluxes between the atmosphere and land. Knowledge of these should enable improved water budgets.
- This information should also be useful for carbon cycle modeling and determining whether some areas are sources or sinks of carbon.

Explicitly state the advantage of using a suborbital platform for this measurement.

- Spatial resolution less than 1 km. Repeat times for overpass of a single area would be less than 3 days.
- Technique for resolving deeper soil moisture may not be employable from space without other technological advancements.
- Resolution of diurnal cycle.
- Sustained mission (>60 days) would begin to capture phenomenon over vegetation life cycles.
- Ability to compare phenomena across spatial scales.

Identify other cross-cutting areas impacted by this observation.

- Instrument & platform capability would be useful for sea surface salinity.
- Useful for biomass mapping
- Data useful to weather for antecedent conditions requirement.
- Validation capability for Orbital systems
- Risk mitigation for future <1km soil moisture measurement capability for NPOESS system requirement

Water & Energy Cycles – Soil Moisture & Freeze/Thaw states

<u>Observation / Measurement System Requirements</u>: Describe how you want to observe or measure the phenomena. Consider the following:

Instrument / Payload characteristics (type, weight, volume, environmental considerations, and access such as sampling or viewing ports)

1. Active/Passive microwave instrument having L and P bands and potentially longer wavelengths. Multipolarization and conical scanning desired.
2. Less than 200kg. Volume dictated by antenna size (antenna area required is 1-5 sq. meters).
3. Environmental considerations – could be limited to fair weather.
4. Power – depends upon instrument, 1-5 Kilowatts.

Flight characteristics (location, altitude, endurance, season, frequency). Discuss number of platforms, formation flying, or other special flight characteristics.

- Location – 40°S – 70°N
- Altitude – dependent on observation scale. Range of 1-10 km, but okay to go higher at times.
- Endurance and Frequency – duty cycle should be 70-80% of a week for "local" usage. For remote usage, require 24 hours, 2-3 times a week over target area, though using a "local" airport would help.
- Season – local spring-summer-fall in extra-tropics. All year in tropics.
- Single platform.
- Precise ground track knowledge required (<10 m). Control less important. Pointing accuracy for instrument needs to be <0.1 degrees.

- Geographic areas of interest would include all land areas, except those permanently covered by snow or ice.

Communication needs such as real-time data or instrument control

- Low data rate Housekeeping data (with back and forth communication) would be required.
- Real-time data not required for scientific research, however, information might be useful for real time decision makers so this capability might be required after instrument proves itself.
- Autonomy and pre-plan flight plans.
- High speed downloads required upon landing. Note that this would thus mandate sufficient data storage on board. Combine aircraft state data with instrument data, including time tags.

Water & Energy Cycles – Soil Moisture & Freeze/Thaw states

<u>Mission Concept</u>: Describe in as much detail as possible the measurement approach:

Provide a narrative describing a "day-in-the-life" of the mission.

- [Assumption is that this is a single aircraft entity. "day-in-the-life" might change were this a multiple platform mission.]

- Aircraft, instrument(s), and team members can go to host airport separately. Once there, instrument(s) would be integrated into the aircraft if not pre-integrated. Calibration flight(s) and resolution of anomalies would be required. Aircraft receives instructions for individual flight mission.

- Aircraft takes off and ferries to target location. At target, aircraft either makes circles over points or series of flight lines. This might include changing altitudes between circles/passes.

- Between sets of circles or passes the aircraft, sensor and mission control, go through a series of checks to determine if re-flying over a set area is required.
- Such as encountering error flags in data retrieval, strong crosswinds (location disruption), RFI errors, review of complimentary sensor data – which might require subsequent alteration of sensor specifications or flight paths.

- All signals from command control to aircraft while on route would be choices from a pre-set list of commands (or series of commands).

- Upon completion of programmed time period, or mission control signal, aircraft returns to host airport. Complete data (see above) is downloaded or removed rapidly from the aircraft. Aircraft is prepared for subsequent mission.

Develop a diagram showing flight profile or maneuvers in time, space and/or geographic coordinates.

- This isn't really a critical component as flight profiles would be rather germane, e.g. simpler flight paths.

Water & Energy Cycles – Soil Moisture & Freeze/Thaw states

Identify any special or unique platform or mission issues

- As stated this "mission" concept is mostly to retrieve soil moisture information for research science. There are other abilities (of the UAV sensor tandem) that could be employed for other purposes. For example, giving soil moisture information to weather forecasters or doing floodplain mapping (essentially looking for very high soil moisture) these things would require extra requirements for UAV platform. For example, being able to re-program the fly path in mid-mission, or being able to download the information during mid-mission.

- This mission design would require new sensor development. This development would have to be done in concert with UAV and science priority evolution.

- This mission as defined here is mostly for UAV development to be used in "NASA Earth Science" first and "applications 2nd". If the UAV development should be directed to partner agencies, it would require some of the enhancements mentioned (real-time data download, changeable flight plans during the mission).

Summarize the key elements of the mission concept for this measurement.

- Ability to stay up for 24 hours and carry the active/passive system defined.

Water & Energy Cycles

Key Messages

- Ability for UAV's to do drop sondes or drop-buoys is exciting new potential… beyond bounds of what we would currently consider

- Science now requires routine, large-scale ubiquitous monitoring… Entails from the outset having better discussions with partnering Agencies… Other Agencies are ready for the data from observations we take almost as soon as we take it

- A large number of UAV's will be required for large-scale, ubiquitous monitoring or measurements, rapid response

- Need to do better work on developing roadmaps for the development and operation of both UAV's and instruments:
  - What is the life-cycle of these UAV's?
  - What are the off-ramps?
  - Need partnerships right from the very beginning
  - Even though we "pass off" UAV's to other Agencies, we may want them back at some point… We need "on ramps" to bring them back
  - Involve commercial entities in these partnerships as well

- Monitor the diurnal cycle… All parts of 24 or 48-hr. cycle… holds a lot of potential… Will help us make the next critical science breakthroughs